Conference Paper

Climate and Grazing Effects on the Biomass and Photosynthetic Capacity of Dominant Species in Mongolia Steppe Communities

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Abstract

Global climate change and grazing are the key factors affecting plant productivity in steppe regions of Mongolia. It is important to separate the impacts of these factors and to assess the contribution of each factor to the biomass of pastoral plants. Here, we studied the grazing and climate impact on biomass and functional traits in three dominant species of Mongolian steppe plant communities: *Artemisia frigida* Willd., *Stipa krylovii* Roshev., and *Kochia prostrata* (L.) Schrad. Both aridity and grazing significantly influenced the biomass of the studied species but the direction and scope of the changes were species-specific. Grazing had no effect on leaf mass per area (LMA), photosynthesis (A_{max}) and the content of photosynthetic pigments. An increase in climate aridity resulted in enhancing A_{max} for C_4-plant *K. prostrata*, but its decline in C_3-species *A. frigida* and *S. krylovii*. *K. prostrata* showed the decrease in leaf dry matter content (LDMC) and water-use efficiency (WUE) under grazing. The authors conclude that: (1) both climate aridity and grazing have a significant influence on plant productivity and that they act on different groups of functional traits and (2) plants' response to the combined effect of these factors depends on the functional properties of the species.

Keywords: aridity, grazing, dominants, photosynthesis, chlorophyll, steppe, Mongolia

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1. Introduction

Climate aridity and grazing are among the most significant ecological factors affecting the structure and composition of Mongolian steppe plant communities [1, 2]. The combined action of these two processes in Mongolia leads to the expansion of alkaloid plants, the invasion of shrub species into automorphic ecosystems and, accordingly, the extrusion of dominant herbaceous species from steppe communities [1]. It is well known that both factors – climate and grazing – may influence the physiology and productivity of pastoral plants. The enhancement of dryness may lead to changes in gas exchange rate and productivity [3]. Increasingly, grazing usually leads to biomass loss [2, 4]. At the same time, it is still unclear which of the two factors often associated to each other is crucial for vegetation. There are few data on the combined effect of aridity and grazing on plants [2, 5, 6]. The mechanisms of different factors on photosynthesis and productivity is the key question in the assessment and prediction of plant resources in steppe ecosystems.

The aim of this work is to investigate the effect of aridity and grazing on the biomass and functional traits of steppe plants in Mongolia. We hypothesized that these two factors may influence plant productivity in different ways and may involve different groups of plant functional traits. To test this hypothesis, we studied three dominant steppe species in different climatic regions: in each of them, plants in the presence and absence of grazing were analyzed.

2. Methods

The studies were conducted at 4 sites located in different regions of the Mongolia steppes (Table 1). Within each site, plants were sampled in two variants – intensive grazing and grazing exclusion (Figure 1). The experimental areas with grazing exclusion were fenced areas of about 0.5–1 ha located along the railway and isolated from domestic animals by a metal grid fence. Sites with intensive grazing were located directly next to the fenced areas. Three widespread and abundant species of natural steppe communities (*Artemisia frigida, Stipa krylovii, Kochia prostrata*) were chosen for analysis. Each species was studied in two geographical sites (Table 1). For 10 individuals of each species, the aboveground biomass and leaf traits were determined. Leaf area and leaf mass per area (LMA) were measured using computing image analysis (SIAMS, Russia) and weighing. Photosynthetic and transpiration rates and water use efficiency (WUE) were determined for 5 plants per variant using the portable photosynthetic

system Li-6400 XT (Li-COR, USA) under a saturated light of 1500μmol/m^2s, a chamber temperature of 24 °C and an ambient concentration of CO_2. Photosynthetic pigment content (chlorophylls *a* and *b*, carotenoids) were measured in 5 replicates using the spectrophotometer Odyssey DR/2500 (Hach, USA) after extraction in 80% acetone.

Table 1: Geographical location, climatic and vegetation characteristics of the study sites. MAP, mean annual precipitation (mm); MAT, mean annual temperature (°C); *I*a, aridity index: *I*a = MAP/(MAT + 10) [7, 8]. Af – *Artemisia frigida*, Kp – *Kochia prostrata*, Sk – *Stipa krylovii*.

Site	Coordinates	Vegetation Zone	MAP	MAT	Ia	Study Species
A1	N 47°41′39.5″ E 107°12′07″	Dry steppe	241	−0.76	26.1	Af
A2	N 47°34′38″ E 107°17′10.4″	True steppe	235	−1.02	26.2	Sk
A3	N 46°09′41.7″ E 108°36′29.2″	Desert steppe	189	1.18	16.9	Af, Sk, Kp
A4	N 45°56′4.1″ E 108°59′21.9″	Desert steppe	182	1.70	15.6	Kp

Figure 1: Photo of site A4 illustrating the studied areas excluding grazing (to the left of the fence) and with intensive grazing (to the right of the fence). Source: Authors' own work.

3. Results

The analysis of the aboveground biomass showed the negative effect of grazing on plant biomass, except *A. frigida* in desert steppe (point A3) (Figure 2). The increase in aridity led to the decline of biomass of *K. prostrata* in both variants of grazing intensity

and for *A. frigida* in the variant of grazing exclusion. The increase in aridity did not affect the biomass *of S. krylovii*. On the contrary, the biomass of this species in a drier climate was slightly higher. Grazing resulted in a significant reduction of the above-ground biomass of this species by two to three times. Other authors have also shown a considerable decrease in plant height and biomass for steppe plants under grazing [4, 9, 10]. Thus, both grazing and aridity influence the biomass of the studied species, but the direction and the degree of changes are species-specific, a fact confirmed by the results of variance analysis (ANOVA) (Figure 2). In our opinion, the response of the species to the impact of these environmental factors depends on its functional properties, primarily on the growth form and biochemical type of photosynthesis. The studied dominant species of steppe communities differ in their functional properties. *S. krylovii* is a herbaceous plant with a superficial root system that is directly dependent on the soil water content, while *A. frigida* and *K. prostrata* are shrubs with deeper root systems. On the other hand, *K. prostrata* belongs to plants with C_4-type of photosynthesis, possessing a number of physiological advantages in comparison to C_3-plants for successful growth in arid climates, such as high water and nitrogen use efficiency, large internal CO_2 conductance, low values of carbon dioxide compensation point, higher temperature and light optimum of photosynthesis, etc. [11–14]. In this regard, the abundance of C_4-species increases with aridity, while the abundance of C_3-species declines [15]. Accordingly, C_3- and C_4-plants differ in functional traits and in response to climate. Indeed, the C_4-species *K. prostrata* differed from the C_3-plants *A. frigida* and *S. krylovii* in terms of lower LDMC, greater LMA and higher photosynthetic rate (Figure 2).

An increase in climate aridity led to an enhancing of photosynthesis and transpiration rates for *K. prostrata*: however, for *A. frigida* they decreased and for *S. krylovii* remained stable. Meanwhile, high levels of grazing did not influence the rate of leaf gas exchange in the studied species. Grazing also did not affect the photosynthetic pigment content, which, like photosynthesis, was largely dependent on climate aridity. Wang et al. [10] also demonstrated the absence of grazing influence on functional traits closely linked with photosynthesis, such as nitrogen content per leaf mass and area. In more arid conditions, *A. frigida* and *S. krylovii* showed an increase in chlorophyll content per unit leaf area by 1.6–2.0 times due to the increase in LMA (*A. frigida*) or leaf thickness (*S. krylovii*). As in the case with aboveground biomass, both aridity and grazing influenced integral functional traits like water use efficiency (WUE). This parameter indicates the amount of transpiration loses per unit of assimilated carbon dioxide and is one of the indicators of plant tolerance to drought [16]. The increasing

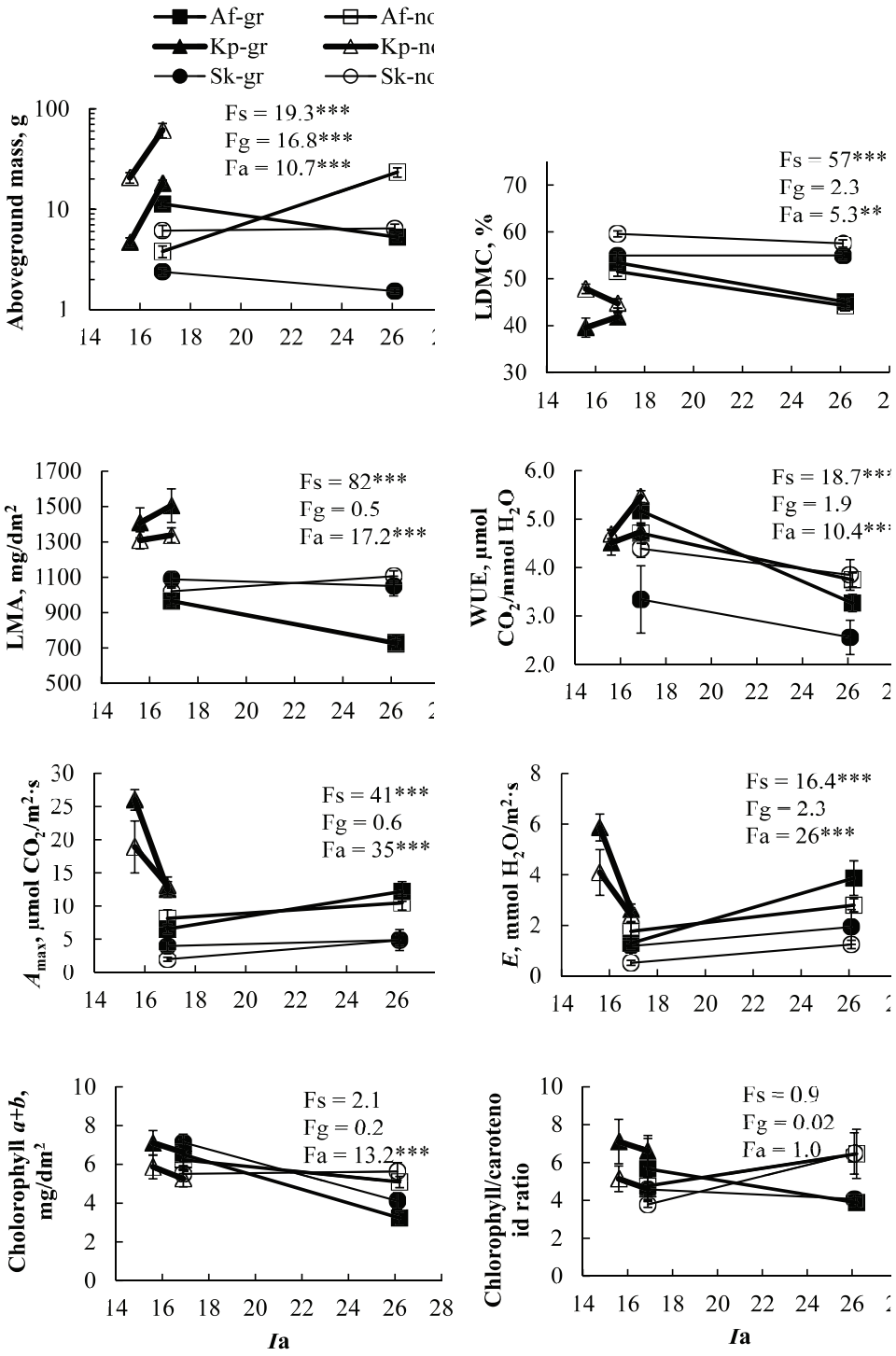

Figure 2: Intraspecific variation of plant functional traits in dependence on climate aridity and grazing. *X*-axis presents the values of aridity index (*Ia*). Line types and symbols show different species and variants of grazing intensity. gr – grazing, no – no grazing. Af – *Artemisia frigida*, Kp – *Kochia prostrata*, Sk – *Stipa krylovii*. LDMC – leaf dry matter content, LMA – leaf mass per area, WUE – water use efficiency, A_{max} – rate of CO_2 uptake, *E* – transpiration rate. The results of one-way ANOVA are presented: F_s–*F*-statistics to test the influence of interspecific differences (species-specific effect) in trait variation; F_g–*F*-statistics to test the influence of grazing (grazing effect); F_a– *F*-statistics to test the influence of climate (aridity effect). ** $P \leq 0.01$; ***, $P \leq 0.001$. Source: Authors' own work.

aridity caused an enhancing of WUE for C_3-species *A. frigid* and *S. krylovii*, and a small decrease in this parameter for the C_4-species *K. prostrata*. In contrast, grazing caused the greatest decrease in WUE for *K. prostrate* and *S. krylovii*, while *A. frigida* did not significantly depend on grazing due to high variation within each site. The studied species possessed different mechanisms of WUE regulation, connected with different structural and functional leaf restructuring due to changing climate and grazing. A deep root system, C_4-photosynthesis and the presence of water storage tissue allow this species to maintain high photosynthetic rates (A_{max}) and WUE when under increasing arid stress. The decrease of WUE under grazing for this species was accompanied by an increase in leaf thickness and water content: this allows it to reduce stomatal control over transpiration and to increase the rate of CO_2 uptake from ambient air to the leaf. WUE increased with aridity in *Artemisia frigida* due to a two-fold reduction in transpiration. The increase of pigment concentration in the leaf allows it to minimize the drop in photosynthesis. The opportunity for transpiration loss decrease in this species was conditioned by structural changes in the leaves, which become denser and harder in more arid conditions. The increase of WUE in *A. frigida* caused the effective regulation of biomass accumulation when under increasing arid stress. *Stipa krylovii* was characterized by the lowest rate of gas exchange and the highest LDMC among all the studied species. Grazing led to an increase in leaf water content in *A. frigida*, which in turn caused a decline in WUE: along with the loss of biomass during grazing, this could lead to a decrease in plant productivity.

4. Conclusion

The studied species belong to widespread dominants in the steppes of Mongolia, so the revealed regularities and mechanisms allow us to predict the response of steppe vegetation to climate aridity and grazing in general. Our results demonstrate that both aridity and grazing affect plant productivity, but at the same time each factor influences different groups of functional traits. Climate change affects leaf traits and plant photosynthetic capacity, while disturbance by grazing leads to physical biomass loss and changes in water balance. Plant response to the combined effect of aridity and grazing depends on species' functional traits, which are determined by their biochemical and physiological characteristics.

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References

[1] Gunin, P. D., Bazha, S. N., Danzhalova, E. V., et al. (2015). Regional features of desertification processes of ecosystems on the border of the Baikal Basin and Central Asian Internal Drainage Basin. *Arid Ecosystems*, vol. 5, no. 3, pp. 117–133.

[2] Xie, L.-N., Guo, H.-Y., Chen, W.-Z., et al. (2018). Effects of grazing on population growth characteristics of *Caragana stenophylla* along a climatic aridity gradient. Rangeland Ecology & Management, vol. 71, no. 1, pp. 98–105.

[3] Reich, P. B., Wright, I., Cavender-Bares, J., et al. (2003). The evolution of plant functional variation: Traits, spectra, and strategies. *International Journal of Plant Sciences*, vol. 164, pp. 143–164.

[4] Asner, G. P., Elmore, A. J., Olander, L. P., et al. (2004). Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources,* vol. 29, pp. 261–299.

[5] Havstad, K. M., Herrick, J. E., and Tseelei, E. (2008). Mongolia's rangelands: Is livestock production the key to the future? *Frontiers in Ecology and the Environment*, vol. 6, pp. 386–391.

[6] Hunt, L. P. (2010). Spatial variation in the demography and population dynamics of a perennial shrub (*Atriplex vesicaria*) under sheep grazing in semi-arid Australian rangelands. *Austral Ecology*, vol. 35, pp. 794–805.

[7] Matsuura, K. and Willmott, C. J. (2012). *Terrestrial Air Temperature: 1900–2010 Gridded Monthly Time Series*. Retrieved from http://climate.geog.udel.edu/$\sim$climate/html_pages/Global2011/README.GlobalTsT2011.html

[8] Matsuura, K. and Willmott, C. J. (2012). *Terrestrial Precipitation: 1900–2010 Gridded Monthly Time Series*. Retrieved from http://climate.geog.udel.edu/$\sim$climate/html_pages/Global2011/Precip_revised_3.02/README.GlobalTsP2011.html

[9] Huntly, N. (1991). Herbivores and the dynamics of communities and ecosystems. *Annual Review of Ecology and Systematics*, vol. 22, pp. 477–503.

[10] Wang, J., Zhong, M., Wu, R., et al. (2016). Response of plant functional traits to grazing for three dominant species in alpine steppe habitat of the Qinghai–Tibet Plateau, China. *Ecological Research*, vol. 31, no. 4, pp. 515–524.

[11] Black, C. C. (1971). Ecological implications of dividing plants into groups with distinct photosynthetic production capacity. *Advances in Ecological Research*, vol. 7, pp. 87–114.

[12] Black, C. C. (1973). Photosynthetic carbon fixation in relation to net CO_2 uptake. Annual Review of Plant Physiology, vol. 24, pp. 253–286.

[13] Ehleringer, J. R. (1978). Implications of quantum yield differences to the distributions of C_3 and C_4 grasses. *Oecologia*, vol. 31, pp. 255–267.

[14] Ehleringer, J. R., Cerling, T. E., and Helliker, B. R. (1997). C_4 photosynthesis, atmospheric CO_2, and climate. *Oecologia*, vol. 112, pp. 285–299.

[15] Pyankov, V. I., Gunin, P. D., S. Tsoog, et al. (2000). C_4 plants in the vegetation of Mongolia: Their natural occurrence and geographical distribution in relation to climate. *Oecologia*, vol. 123, pp. 1–31.

[16] Lambers, H., Chapin F. S., III, and Pons, T. L. (1998). *Plant Physiological Ecology*. New York, NY: Springer-Verlag.